DARPA

2

AD-A227 498

Advanced Technology Tactical Transport (ATTT)

SRS TECHNOLOGIES

1500 WILSON BLVD., SUITE 800
P.O. BOX 12707
ARLINGTON, VIRGINIA 22209-8707

(703) 522-5588

WASHINGTON OPERATIONS

MDA 972-88-C-0046

AT3

DARPA

Advanced Technology Tactical Transport (ATTT)

SRS TECHNOLOGIES

1500 WILSON BLVD., SUITE 800
P.O. BOX 12707
ARLINGTON, VIRGINIA 22209-8707

(703) 522-5588

WASHINGTON OPERATIONS

MDA 972-88-C-0046

AT3

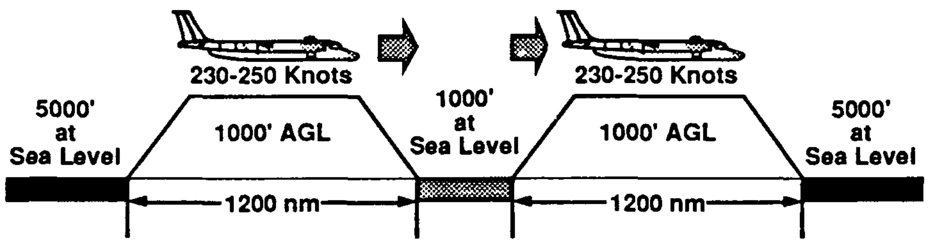
Advanced Technology Tactical Transport (ATTT)

Airlift for Special Operations Forces (SOF) has received a great deal of attention since the early 1980's. Possibly the most difficult SOF mission is long-range infiltration and exfiltration of small forces deep behind enemy lines. In an effort sponsored and funded by OSD, DARPA has conducted a program to investigate unique applications of aeronautical technology to address this mission.

Starting with a design feasibility study in 1984 by Scaled Composites, Incorporated, the Advanced Technology Tactical Transport program has attempted to provide a solution to the infiltration/exfiltration task. In addition, DARPA has structured the program to gain important insight into innovative development methods.

Mission Profile

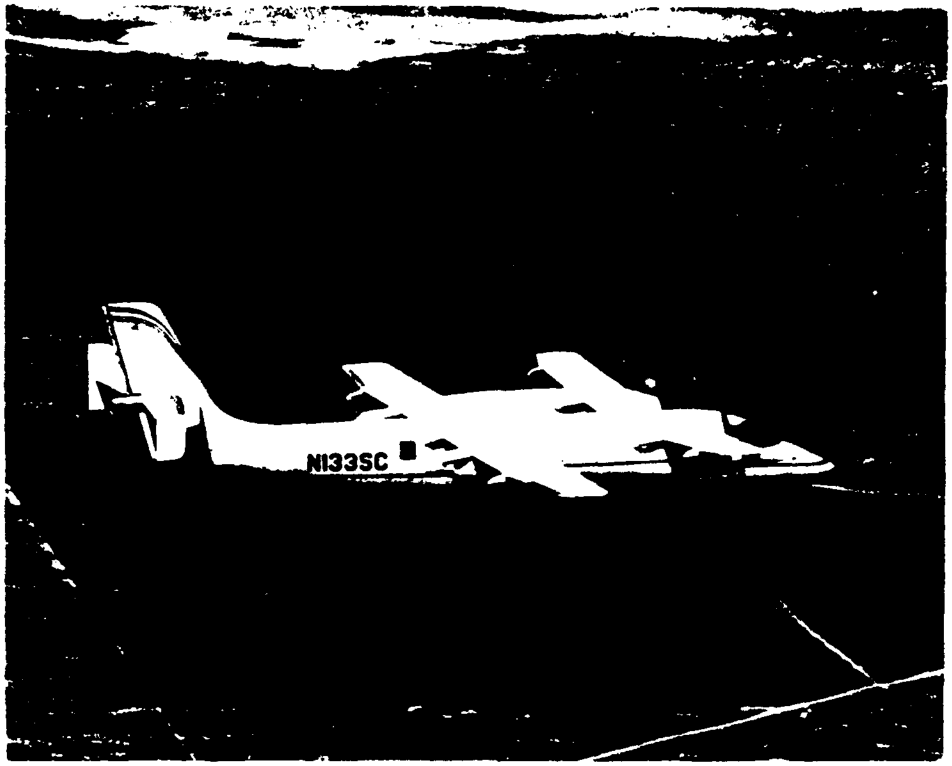
- ❑ 8500 Pound Payload
  - Passengers (3500 Lb)
  - 5000 Lb Cargo
- ❑ 2400 nm Round Trip
  - Departure/Arrival Runway: 5000 Feet
  - Cruise at 1000 Feet Above Ground Level (AGL)
  - Mid Point Landing, No Refueling
- ❑ Mid Point Landing
  - 1000 Feet, Unprepared Surface
  - Unload/Reload, No Payload Reduction



As seen in the mission profile, the task requires a combination of very long-range, unrefueled, low-altitude flight with outstanding short-field landing and take-off performance. Desired airspeed was greater than 250 knots, with 230 knots as the minimum.

Scaled Composites chose a tandem wing design to provide the required lift and wing tank fuel capacity, without excess structural weight, for a 2400 nm range. A unique, relatively complex, wing flap system helped to provide the short field capability. The remainder of this briefing explains the important results of the proof-of-concept phase of the ATTT program.

ATTT - Original Configuration



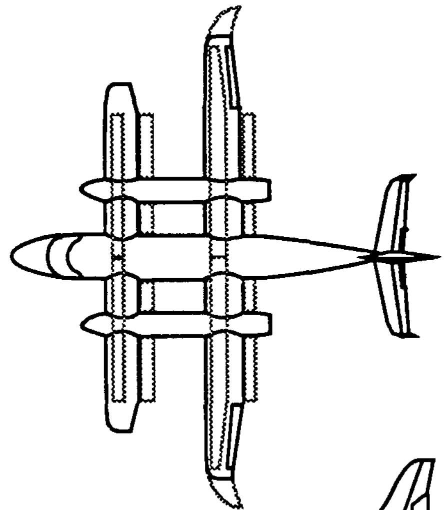
Under contract to DARPA, Scaled Composites Inc. (SCI) constructed a 62% scale *Advanced Technology Tactical Transport* (ATTT) Proof-of-Concept (POC) aircraft.

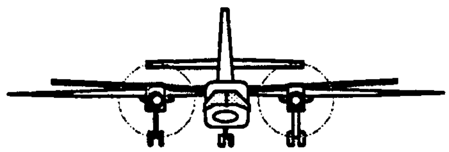
DARPA used the ATTT program as a method for what the Packard Commission called rapid prototyping. That is, the DARPA ATTT program is an investigation of how the system acquisition process can be improved through the use of prototypes or demonstrators in the early conceptual and preliminary design stages of the acquisition process.

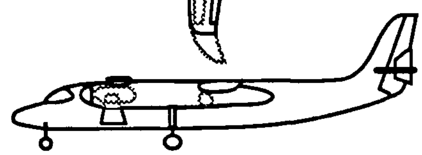
The first configuration of the ATTT POC aircraft was flight tested between December 1987 and November 1988. The first flight test report, covering the baseline aircraft development and performance, was published in November 1988. The aircraft was subsequently modified and a second phase of flight tests was conducted between April and July of 1989. The final flight test report was published in September of 1989.

62% Scaled Aircraft-Cruciform Tail

POC Aircraft	Dimensions
Forward wing Span:	37.67 Feet
Aft Wing Span (With Original Tips):	47.54 Feet
Aft Wing Span (With Sheared Tips):	53.17 Feet
Total Wing Area:	297.56 Sq. Feet
Length:	44.17 Feet
Height:	16.0 Feet







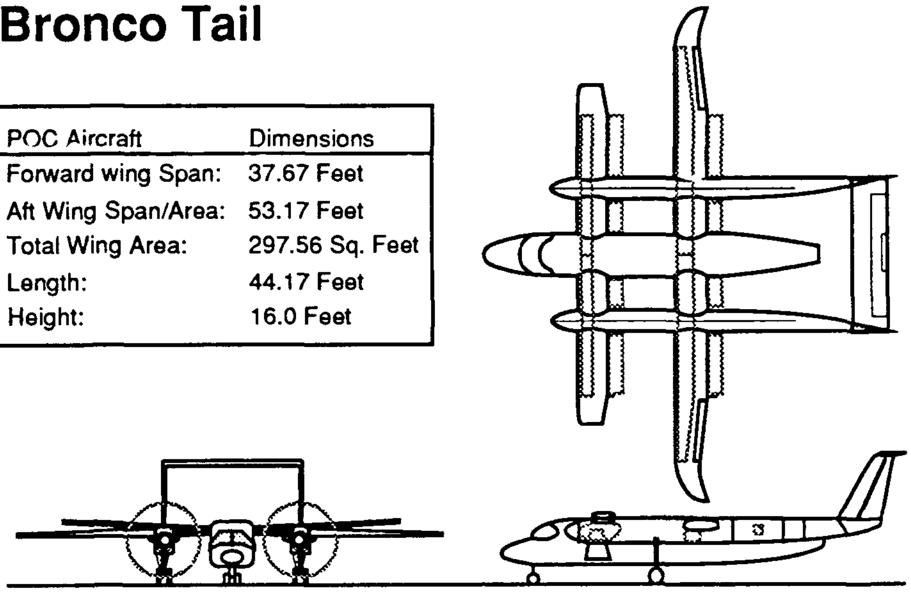
The ATTT design is not a showcase for recent, dramatic technology advances, but rather an attempt to apply available technology to a particular and difficult tactical mission.

To provide the necessary internal fuel volume for long range missions, the ATTT design used a tandem-wing configuration with twin engine nacelles. Short takeoff/landing (STOL) capabilities were enhanced by a unique flap arrangement on both wings. Neither of these features had previously been tested in a wind tunnel or in flight.

The 62% scale proof-of-concept aircraft was intended to simultaneously validate the predictions and the aerodynamic characteristics of this configuration and obtain as much applicable flight test data as possible to support full-scale development.

62% Scaled Aircraft-Bronco Tail

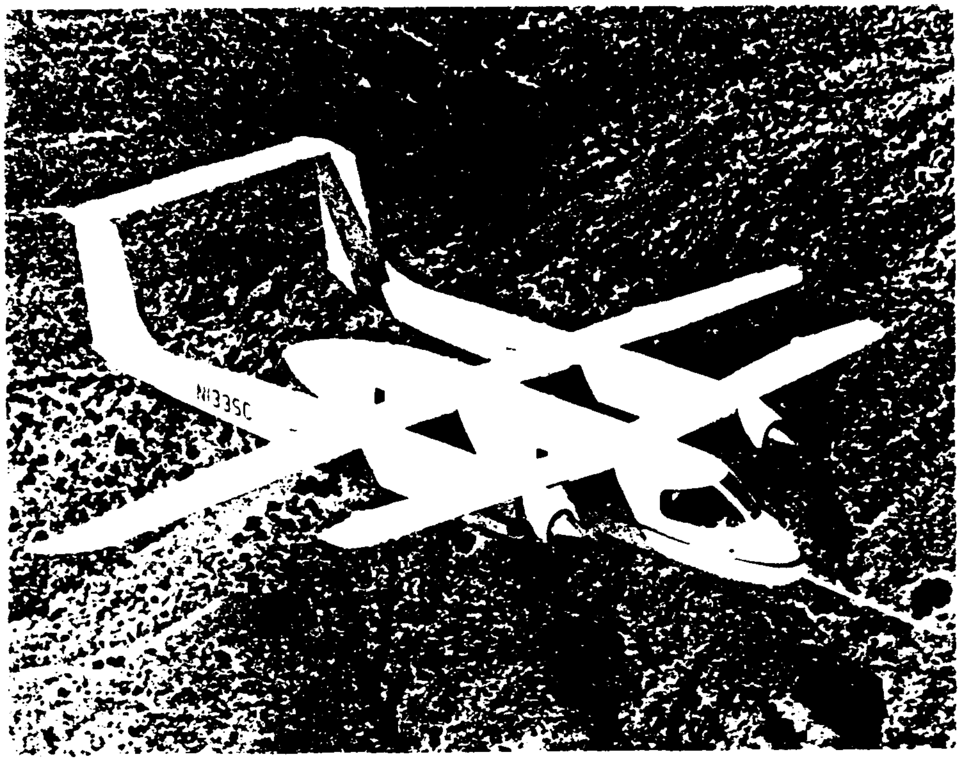
POC Aircraft	Dimensions
Forward wing Span:	37.67 Feet
Aft Wing Span/Area:	53.17 Feet
Total Wing Area:	297.56 Sq. Feet
Length:	44.17 Feet
Height:	16.0 Feet



Analysis of the flight test results of the "Cruciform Tail" configuration disclosed a significant deficiency in the directional stability and engine-out minimum control speed of the airplane as well as some perceived loading difficulties due to low clearance of the aft cargo door. A major redesign and modification to the basic aircraft configuration was then undertaken.

The two engine nacelles were extended aft and configured with a vertical tail on each side. A new horizontal tail was designed to set atop the two vertical tails in a configuration similar to that of the OV-10 "Bronco," thus the name, "Bronco Tail" configuration.

Bronco Tail ATTT



The time required to accomplish the modification from the "Cruciform Tail" configuration to the "Bronco Tail" configuration was a mere four months. The final test results showed significant improvements in both directional stability and engine-out minimum control speed with no loss in performance.

The aerodynamic lift and drag characteristics of the tandem-wing ATTT are quite similar to those of the single-wing C-130. The ATTT, however, is capable of carrying 31% more internal fuel than the C-130 configuration scaled to the same wing area.

Structure

- ❑ All-Composite Construction
  - Ease of manufacture and modification.
- ❑ Static Load Test
  - Flight components loaded to design.
  - Flight test limited to 80% of design.
- ❑ Dynamic Load Test
  - Ground Vibration Test (GVT).
  - Flutter clearance flight test.

The primary reason for the tandem wing/nacelles design was to provide the necessary volume for internal fuel. It also allowed the fuel to be distributed away from the centerline cabin/cargo area. This concentrated the fuel, engine, and landing gear loads in the nacelle with the two wing structures providing a light weight tie-in to the fuselage. For ease of manufacturing and modification, the entire 62% POC aircraft was constructed of composite materials, even though many of the components were quite angular and well suited to more conventional techniques.

Static load tests to the design load factor were performed on both wings before assembly, and on the vertical and horizontal tail after assembly on the fuselage. These tests were repeated after the Bronco tail modification. As is customary when the flight article is also the static test article, the flight test program was restricted to 80% of the demonstrated design load factor.

A ground vibration test (GVT) was performed on the 62% POC aircraft due to the unique structural configuration and concern for coupling between the wing bending modes and the nacelles. Flutter margins were predicted to be adequate by the GVT analysis. Flight tests to clear the flutter envelope were successfully completed on the baseline configuration. No dynamic structural problems were encountered during flight testing.

Subsystems

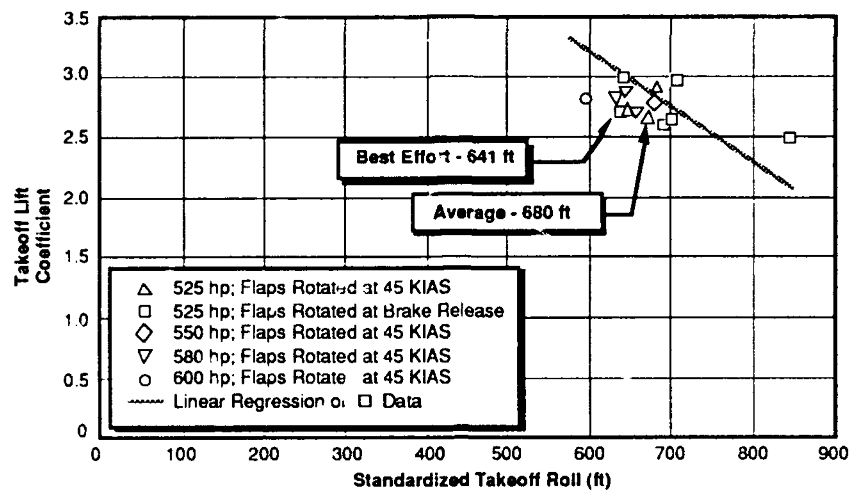
- ❑ Flight Controls
  - Development was required to safely attain POC envelope (not transferable to full-scale)
- ❑ Flaps
  - Complex but trouble free.
- ❑ Other Systems Performed Well
  - Electrical, Fuel, Propulsion, Egress, Communications, etc.

It was anticipated that a boosted, fly-by-wire flight control system would be used on a full scale ATTT. A simple manual control system was designed for the POC aircraft. This control system required extensive rework and modification over the course of the test program in order to retain flight safety and still attain the desired test conditions. This was especially true of the aileron system. All of the control system problems that were encountered were related to the reversible nature of the linkage and would not occur if standard, irreversible hydraulic actuators are used on the full-scale version.

The flap system was unique to the design and its utility was one of the prime program objectives. The fast-acting flap design was all mechanical and quite complex. Complexity was dictated by the large number of independent flap surfaces (eight) and the necessity to insure that large asymmetries did not occur during deployment. In spite of its complexity, the system worked well throughout the test program.

Subsystems in the 62% POC aircraft were not designed for application to full-scale. The designs were basic, simple, and relatively rugged. Most of the subsystems- *electrical, fuel, propulsion, egress, communications, etc.*- performed well over the course of the test program.

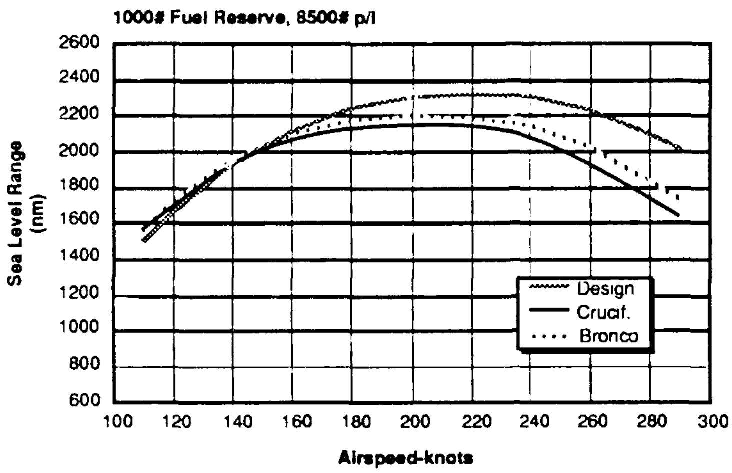
Takeoff Performance



STOL takeoffs at a scaled mid-mission weight were accomplished. Extrapolation of the results to full-scale indicates that a 1000 foot takeoff roll should be obtainable.

Initial concerns about lifting off below Vmca have been alleviated with the Bronco tail. The fast-acting flap feature demonstrated a 10% improvement in ground acceleration distance but did not show a similar improvement in takeoff distance due to the nose-down pitching moment introduce by rapid flap movement immediately before and during the takeoff rotation. Even if takeoff attitude could be achieved, the pitch instability at high power would still be cause for concern.

Predicted Range



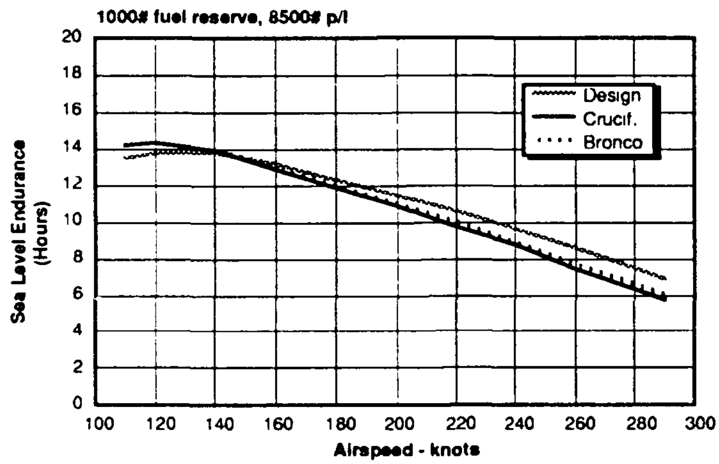
Flight test results indicate the maximum sea level range of a full scale ATTT would be 2200nm and the best cruise speed would be 220 knots.

The sea level range for a full scale ATTT was calculated based on the measured 62% POC aerodynamic flight test data. The variation in specific fuel consumption (sfc) with power setting was empirically determined based on the 62% flight test data for the P&W PT6-135A engines and applied to the specified sea level performance of the G.E. CT64-820-4 engine, the initial candidate engine for the full scale ATTT. Application of this sfc correction to the original design data reduced the design range from 2400 to 2300nm.

Flight test results indicate that the maximum sea level range of the full scale ATTT would be about 2200nm, about 100nm less than the corrected design range.

Best cruise speed would be 220 knots rather than the design speed of 230 knots.

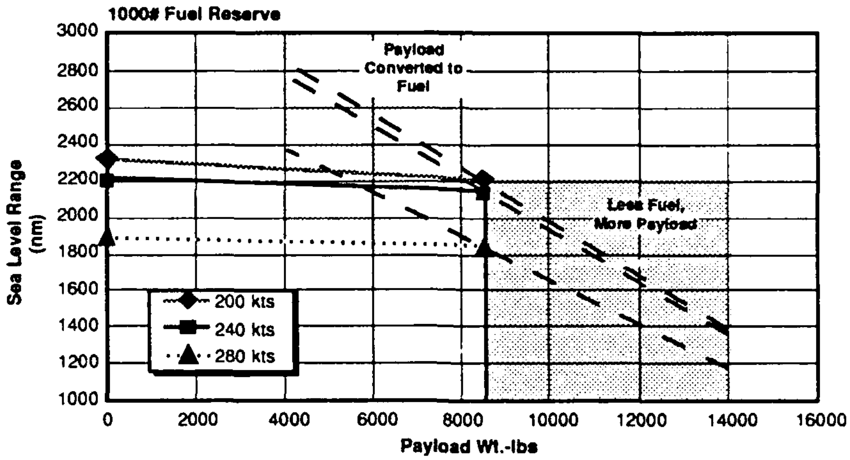
Predicted Endurance



Flight test results indicate endurance of over 12 hours could be routinely achieved.

The sea level endurance for a full-scale ATTT was calculated based on the measured 62% POC aerodynamic flight test data and empirically determined specific fuel consumption characteristics measured on the POC engine. Maximum sea level endurance is over 14 hours, slightly higher than the design point at the best loiter speed of 120 knots, but somewhat less than predicted at the higher speeds.

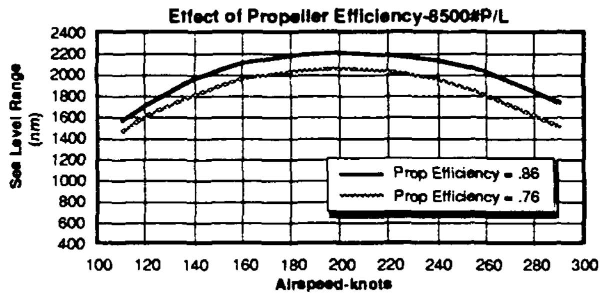
Predicted Range vs. Payload



This chart shows range versus payload for a full scale ATTT. Notice that the range could be extended well beyond the design range by replacing some of the payload in the cargo bay with a ferry fuel tank. High density payloads above the design value of 8500 pounds could also be carried by off-loading fuel to stay within the maximum take-off weight of the airplane.

The trade-off of higher payload weight (concentrated on the aircraft centerline) and lower fuel weight (distributed along the span) could increase wing root bending moments above design values. If carrying high density payloads for shorter ranges is a desirable feature for an ATTT, a temporary external strut could be installed between the fuselage floor and the engine nacelle to distribute the load.

Influence of Propeller Efficiency & SFC

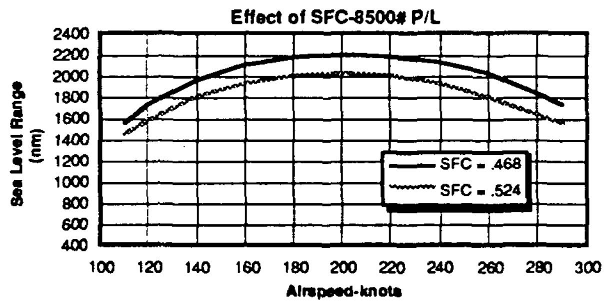


Propeller Efficiency

Sea level range reduced 150nm if only 76% propeller efficiency is achieved

Specific Fuel Consumption

Sea level range reduced 200nm by a 12% increase in SFC

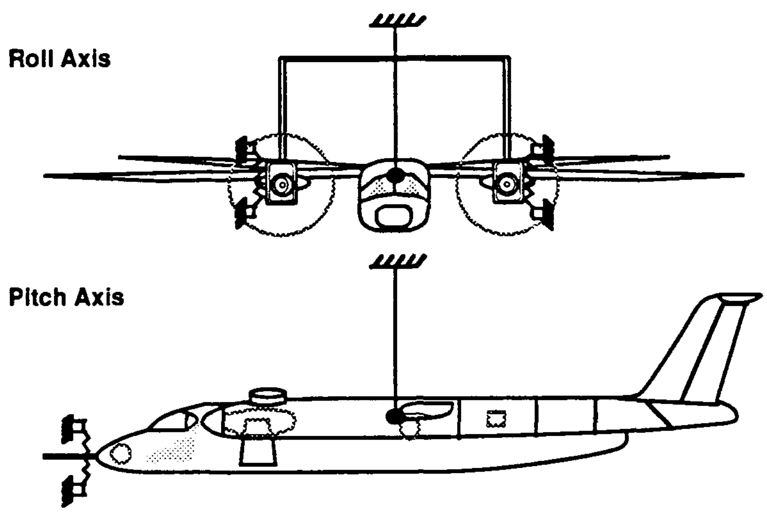


Propeller efficiency and specific fuel consumption are the two most difficult parameters to extrapolate to full scale. These charts show parametric comparisons of the effect of variations in prop efficiency and SFC.

If only 76% propeller efficiency can be achieved rather than the design value of 86%, the maximum sea level range will be reduced from 2200nm to 2050nm, as shown in the top chart.

A 12% increase in specific fuel consumption reduces the sea level range from 2200nm to 2000nm, as shown the lower chart.

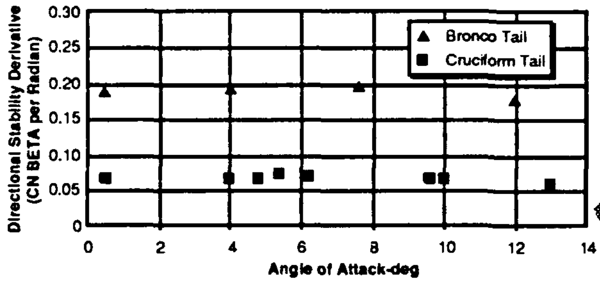
Moments of Inertia Measurement



The accuracy of the absolute values of stability derivatives extracted from dynamic maneuvers is directly related to the accuracy of the aircraft moments of inertia used in the analysis. To provide a valid database for later comparison with wind tunnel tests, it was decided to measure the inertias of the ATTT 62% POC aircraft. Direct measurements of the total aircraft moments of inertia were performed both prior to and after the installation of the Bronco tail.

Since no primary structure existed near the cg of the ATTT configuration, it was possible to cut a hole in the top of the fuselage and suspend the aircraft from its cg by a single cable. Calibrated springs were attached to the aircraft on each axis. Moments of inertia were then computed from the measurement of the frequencies at which the system oscillated in each axis (using the installed instrumentation rate gyros). The direct measure of moments of inertia permitted the stability derivatives to be extracted from the flight test data with reasonably high confidence. This should enhance the value of the flight test data for full-scale development.

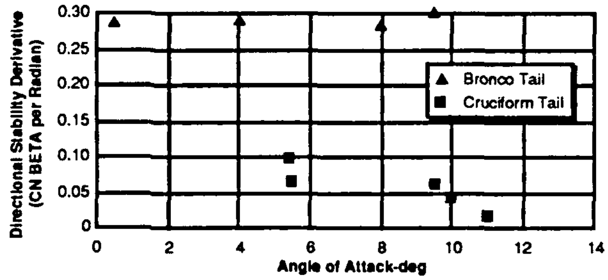
Directional Stability



A significant increase in the directional stability derivative was realized by the Bronco tail modification.

Gear Up/
Forward Flaps Up/
Aft Flaps Up

Gear Up/
Forward Flaps 27°/
Aft Flaps 33°

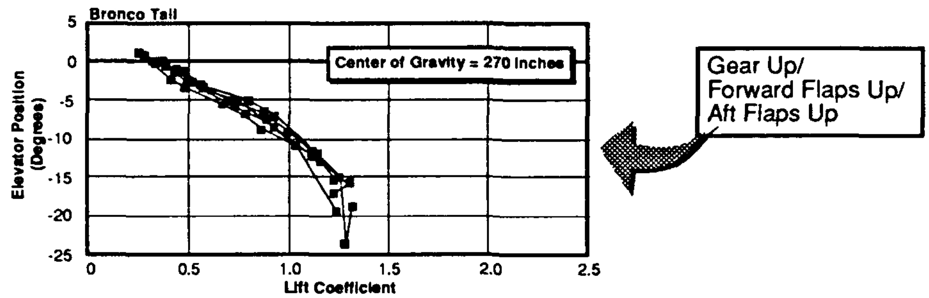


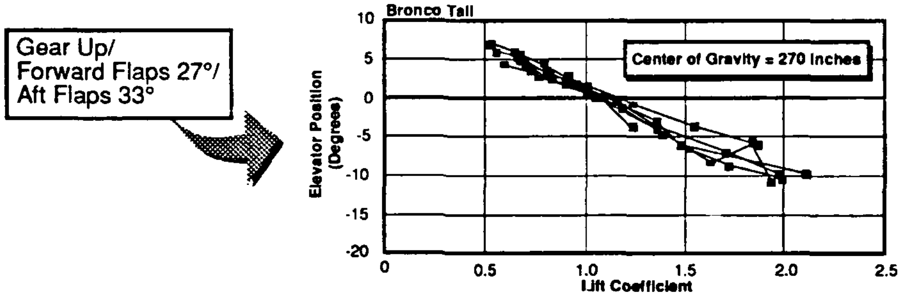
Control doublet maneuvers were performed periodically during the flight test program to extract stability and control derivatives. A manual response-matching technique was used.

The flight-test-derived derivatives were used to assess the affects of configuration changes and to verify test results from standard test techniques such as neutral point determination. By the end of the test program, a relatively complete set of stability derivatives had been obtained on both the cruciform tail and Bronco tail configurations.

The charts above show the significant increase in the directional stability derivative that was realized by the Bronco tail modification.

Static Stability - Idle Power

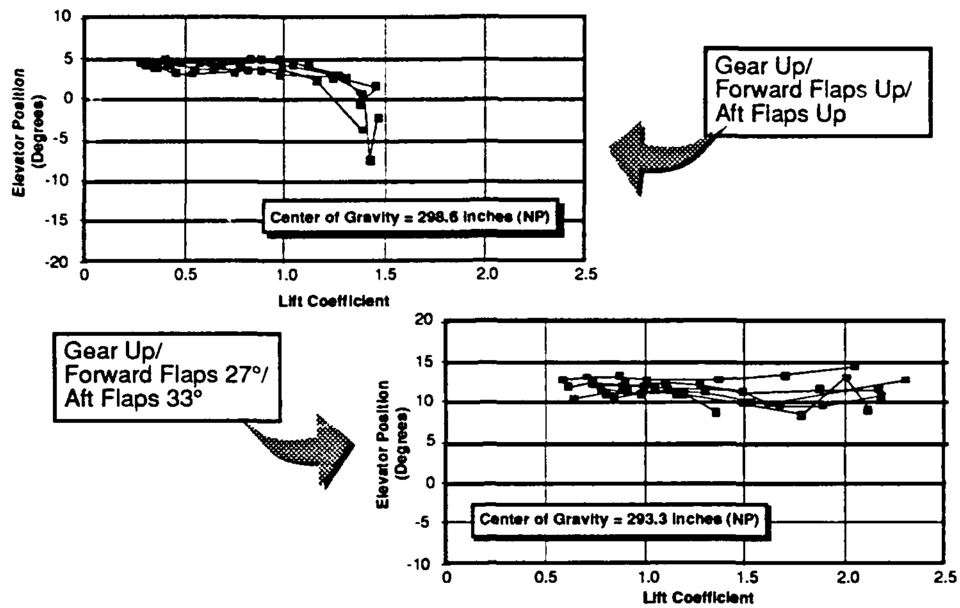




To understand the effects of center of gravity (cg) variation on longitudinal trim, several idle power accelerations and decelerations with widely varying cg conditions were flown and analyzed. The stability derivatives extracted from these dynamic maneuvers were used to correct each test to a common cg. Theoretically, the data points would collapse to a single line.

The results shown in the above charts are consistent and are considered to be within the overall accuracy of the data.

Static Stability - Neutral Point



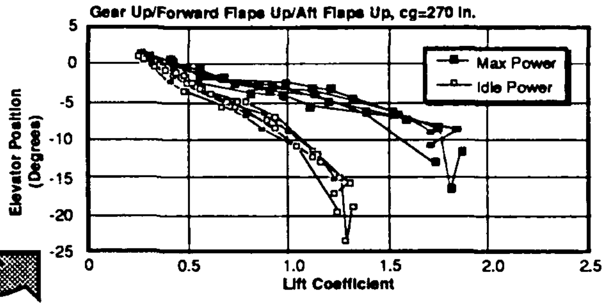
Several idle power accelerations and decelerations were flown with widely varying cg conditions. Longitudinal trim curves were analyzed to validate the neutral point determined by Scaled Composites. The data was corrected to a cg location which corresponded to the neutral point location for that configuration. Theoretically, the data points would collapse to a single horizontal line if the neutral points were accurate.

The resulting curves shown on the charts above corroborate the neutral point determination for low and moderate lift coefficients.

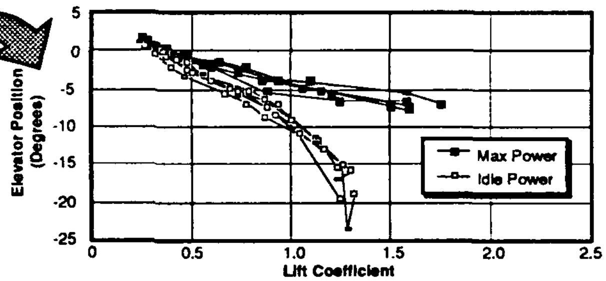
Thrust Effects on Longitudinal Trim - Flaps Up

Analysis of the data produced an empirical relationship between idle trim curves and max power trim curves.

Applying this relationship to several idle power trim curves produced these **PROJECTED MAX** power trim curves.



The **ACTUAL MAX** power trim curves are plotted against the same idle power trim curves in the top chart.



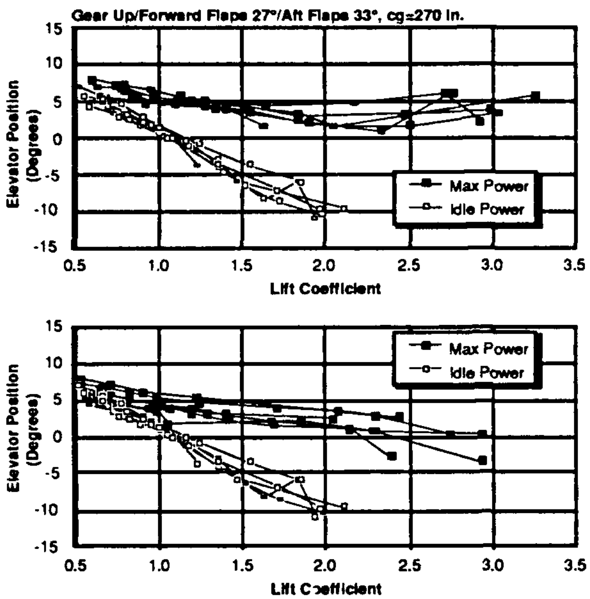
The general trends in the actual max power trim curves are well represented by the projected max power curves.

One of the distinct advantages of the tandem wing twin engine design was the opportunity to place approximately 40% of the effective wing area and 65% of the flapped area within the propeller slipstream for STOL performance. The design lift coefficient of 3 was achieved during the flight test program with flaps down and high power. The conditions, however, were accompanied by a noticeable static pitch instability. The instability is a result of the propeller slipstream producing a larger lift increment on the forward wing (well forward of the cg and immediately behind the prop) than on the aft wing.

Analysis of flight test data produced an empirical relationship between idle power trim curves and max power trim curves. The lift and pitching moment due to thrust were both found to vary with shaft horsepower and with lift coefficient squared. The above charts plot idle power trim curves with *projected* and *actual* max power trim curves.

Although not a precise prediction, the general trends in the actual trim curves are well represented by the projected curves.

Thrust Effects on Longitudinal Trim - Flaps Down



The empirical relationship between idle trim curves and max power trim curves was applied to the flaps-down *configuration.*

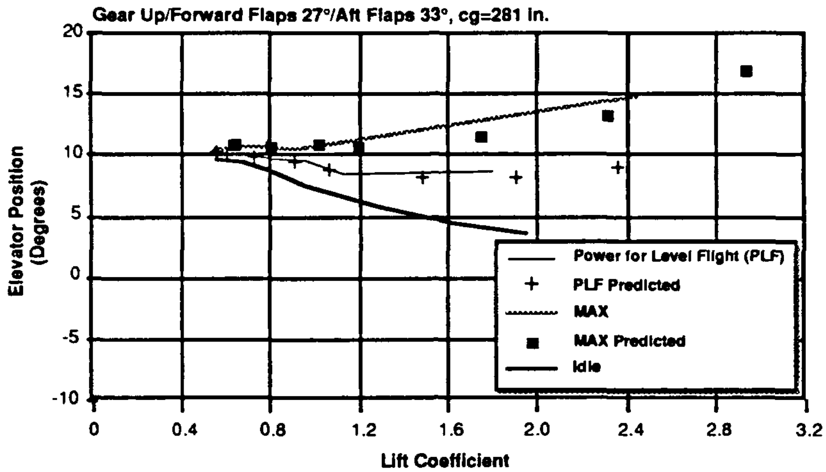
The **PROJECTED** power trim curves (upper chart) are quite similar to the **ACTUAL** power trim curves (lower chart) below a lift coefficient of 2.

The empirical relationship between idle trim curves and max power trim curves discussed on the previous chart was applied to the flaps-down configuration. The results are shown above.

The projected max power trim curves are quite similar to the actual trim curves below a lift coefficient of 2. Above this lift coefficient the airplane experienced buffet and the actual trim curves break in a stable direction.

With flaps down at max power, the airplane is nearly neutrally stable at a nominal cg position of 270 inches.

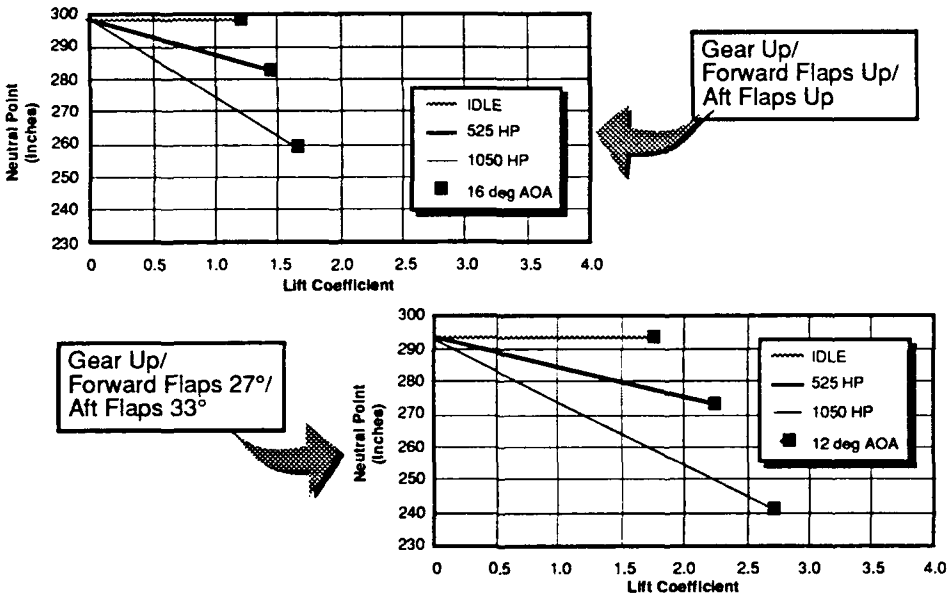
ATTT Thrust Effects - Aft Cg



This chart shows that the longitudinal instability that occurred at max power during one flight with an aft cg position (281 inches) was well predicted by the empirical thrust-effects equation.

Increasing aircraft-nose-down elevator was required as the lift coefficient increased above 1.0, reaching a value of plus 15 degrees before recovery was initiated.

Effect of Thrust on Neutral Point



Adding the thrust-effects equation to the computations of the neutral point generated a new relationship which included the effect of the power setting. The resulting curves for idle, 50% and max power are shown above.

The pitch instability produced by the slipstream effects on a tandem wing at high power settings is a condition which must be addressed if high power STOL performance is to be realized. Active differential control of forward and aft flaps may provide a practical solution to the instability. However, since all of the flap surfaces on the 62% POC aircraft were mechanically linked for safety, it was not possible to investigate active differential control of flaps without major control system modification.

DARPA

Proof-of-Concept Approach

- ❑ Substitute subscale flight test article for early wind tunnel testing
- ❑ Dynamic maneuvers and flight environments not possible in wind tunnels
- ❑ *Key Technology* answers — not *all* answers
- ❑ Fixed-price contract
  - Deliverable flight test report
  - Contractor solely responsible for configuration control and flight safety

The ATTT program established a different approach to the development of a new aircraft configuration. It replaced the conventional wind tunnel and associated development with a subscale flight article. The proof-of-concept aircraft simultaneously accomplished the configuration development normally done in a wind tunnel and obtained flight test data in flight environments. The flight test data included dynamic maneuvers not possible in wind tunnels.

One of the keys to the success was the fact that neither the POC nor the full-scale aircraft needed to venture into the transonic region where flight risks would have been considerably higher without preliminary wind tunnel testing. It remains to be seen whether the design data obtained will truly shorten the time and effort to develop a full scale aircraft. Certainly a great deal of knowledge has been obtained about a generic tandem-wing design.

The procurement method was also new in that the project was done under a fixed price contract with specified payment milestones and with no acceptance specifications or delivery of the aircraft to the government. The contractor retained safety responsibility and all configuration control of the aircraft throughout construction and flight testing with minimal government intervention. The result was a wealth of flight test data on a new configuration for relatively little cost.

AT3

Conclusions

- Design mission is feasible
- Tandem wing exhibited normal handling qualities
- Engine thrust destabilizing in pitch (STOL environment)
- Good flight test database obtained
- POC objectives were achieved
- Relaxation of sea level range requirement would be cause for configuration reassessment
- Production of full-scale prototype would be the next step

The results of the ATTT Proof-of-Concept test program indicate that the design mission is do-able. The tandem wing configuration exhibited conventional performance and handling qualities except for the destabilizing influence of power in the STOL environment. Furthermore, the design and most of the validating data are in place. If this mission, or one of similar range and STOL capabilities is valid, the next step would be construction of a full scale prototype. Certainly a full-scale ATTT in its current configuration would provide a combination STOL/long-range capability which is not currently available. However, significant alterations to the design mission, especially a relaxation of the sea-level range requirement, would call for a reassessment of the applicability of the tandem wing configuration.

Even though the program extended over a considerably longer time than first planned, testing was completed safely, all program objectives achieved, and an impressive volume of actual flight test data was obtained on a unique aerodynamic configuration. For this application, the idea of a proof-of-concept flight article and use of a new procurement process were quite appropriate and successful.